

Unexpected transparency in the scattering of fragile ${}^6\text{Li}$ and ${}^6\text{He}$ Nuclei

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Abstract. It is found that the scattering of the fragile nucleus ${}^6\text{Li}$ from ${}^{12}\text{C}$ and ${}^{16}\text{O}$ is unexpectedly transparent. It is shown that the internal-wave contribution is significantly large in the scattering, which suggests that some transparency could persist in the scattering involving the fragile nucleus ${}^6\text{He}$.

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The nuclear rainbow and the Airy structure in elastic scattering are observed when absorption is incomplete. In the scattering involving magic nuclei like α particle, ${}^{16}\text{O}$ and ${}^{40}\text{Ca}$ absorption is weak and nuclear rainbow has been typically observed in the $\alpha+{}^{16}\text{O}$, $\alpha+{}^{40}\text{Ca}$ [1] and ${}^{16}\text{O}+{}^{16}\text{O}$ systems [2]. For these systems nucleus-nucleus interaction potential has been determined up to the internal region, which made it possible to study the cluster structure of the composite systems ${}^{20}\text{Ne}$, ${}^{44}\text{Ti}$ [1] and ${}^{32}\text{S}$ [3], respectively. For a fragile projectile absorption becomes much stronger. However we show that the Airy structure is observed in the scattering involving a fragile nucleus like ${}^6\text{Li}$ and absorption is incomplete.

${}^6\text{Li} + {}^{16}\text{O}$ elastic scattering shows Anomalous Large Angle Scattering (ALAS) [1] as shown in fig. 1. The experimental data are well reproduced by an optical potential with a squared Woods-Saxon form factor for real and imaginary potentials. This potential is deep similar to a folding model potential and the global optical potential for the $\alpha+{}^{16}\text{O}$ system [1]. By decomposing the calculated scattering amplitude at $E_L=25.7$ and 29.8 MeV into the internal-wave, which penetrates deep into the internal region of the potential, and the barrier-wave reflected at the barrier [4], it is clearly understood that the large cross sections at backward angles are due to the internal-wave contributions. This shows that this scattering is transparent similar to the $\alpha+{}^{16}\text{O}$ system although ${}^6\text{Li}$ is weakly bound. By decomposing the calculated scattering amplitude into farside and nearside components, the angular position of the Airy minimum is identified as shown in fig. 1. For example, the broad dip at $\theta_{c.m.} \simeq 100^\circ$ in the angular distribution for $E_L=29.8$ MeV is an Airy minimum of second order $A2$. For this system unfortunately there are no systematic experimental angular distributions

at high energy region where a typical fall-off of the cross sections appears.

For the ${}^6\text{Li} + {}^{12}\text{C}$ system there are systematic angular distributions for incident energies ranging from a few MeV to 318 MeV. We have analyzed ${}^6\text{Li} + {}^{12}\text{C}$ elastic scattering in the optical model. In fig. 2 the experimental data are well reproduced by a global optical potential. The Airy minima are clearly identified in the angular distributions. Although the target nucleus ${}^{12}\text{C}$ is deformed and easily excited than the ${}^{16}\text{O}$ nucleus, this fragile projectile displays a surprising transparency in the scattering in spite of the important breakup effects. This ALAS may be related to the α -cluster structure of the projectile nucleus and/or the formation of resonances in the intermediate system. We note that the energy evolution of the Airy minimum for the ${}^6\text{Li} + {}^{16}\text{O}$ and ${}^6\text{Li} + {}^{12}\text{C}$ systems shows a similar behaviour, which is also similar to $\alpha+{}^{16}\text{O}$ scattering [1, 5].

The transparency of the ${}^6\text{Li} + {}^{12}\text{C}$ system can be further confirmed by studying the inelastic scattering. In the coupled channel calculation of ${}^{12}\text{C}({}^6\text{Li}, {}^6\text{Li}'){}^{12}\text{C}^*(J^\pi = 2^+, E_x = 4.44 \text{ MeV})$ inelastic scattering by using a collective form factor for ${}^{12}\text{C}$ the experimental angular distributions at $E_L = 24$ and 30 MeV are well reproduced. By decomposing the inelastic scattering amplitude into internal-wave and barrier-wave components in the frame of the DWBA [5], it is found that the contribution of the internal-wave amplitude is very large and the rise of the cross sections beyond $\theta_{c.m.} = 80^\circ$ comes entirely from the internal-wave contributions.

We have also investigated the angular distribution of elastic ${}^6\text{He} + {}^{12}\text{C}$ scattering data at $E_L=18$ MeV [6]. Our potential obtained in the analysis of ${}^6\text{Li} + {}^{12}\text{C}$ scattering at the corresponding energy can reproduce the observed angular distribution, which extends up to $\theta_{c.m.} \simeq 85^\circ$.

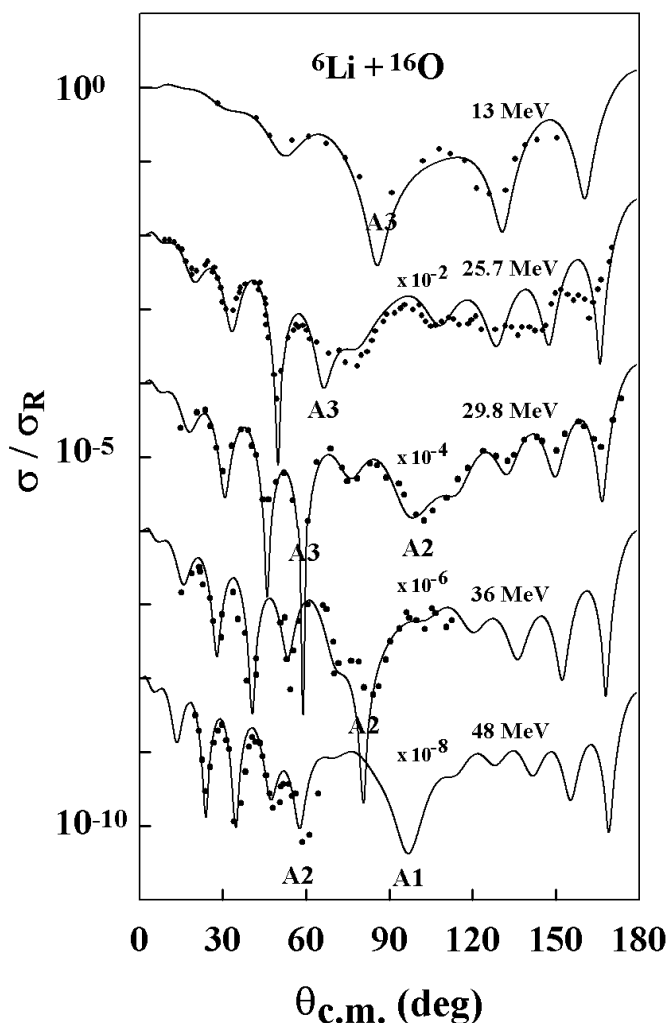


Fig. 1. Comparison of the optical model ${}^6\text{Li}+{}^{16}\text{O}$ cross sections (solid lines) and the experimental angular distributions (filled circles). The potential parameters used are $V_0=316.2$ MeV, $R_R=3.319$ fm, $a_R=0.7$ fm, $R_I=5.822$ fm, and $a_I=0.613$ fm in the conventional notation. W_0 is adjusted to 7, 10, 11.5, 13.5 and 16 MeV for $E_L=13, 25.7, 29.8, 36$ and 48 MeV, respectively. Airy minima are also indicated.

The barrier-wave and internal-wave decomposition of the scattering amplitude shows that significantly large contribution to the backward angles comes from the internal waves, which suggests that transparency could persist in this system. From the similarity between the ${}^6\text{Li}+{}^{12}\text{C}$ system and the ${}^6\text{Li}+{}^{16}\text{O}$ system it is naturally expected that the scattering for the ${}^6\text{He}+{}^{12}\text{C}$ and ${}^6\text{He}+{}^{16}\text{O}$ systems would show a similar behaviour. Therefore it would highly desired to measure the angular distribution for ${}^6\text{He}+{}^{16}\text{O}$ scattering as well as ${}^6\text{He}+{}^{12}\text{C}$ scattering up to large angles in the energy range in fig. 2, which would ascertain whether transparency persists in the scattering of ${}^6\text{He}$ from ${}^{12}\text{C}$ and ${}^{16}\text{O}$. In α particle scattering from ${}^{16}\text{O}$, ${}^{15}\text{N}$ and ${}^{14}\text{C}$, the angular distributions show almost similar behaviour under weak absorption. In fact, the α -nucleus potential for these nuclei is very similar each other and

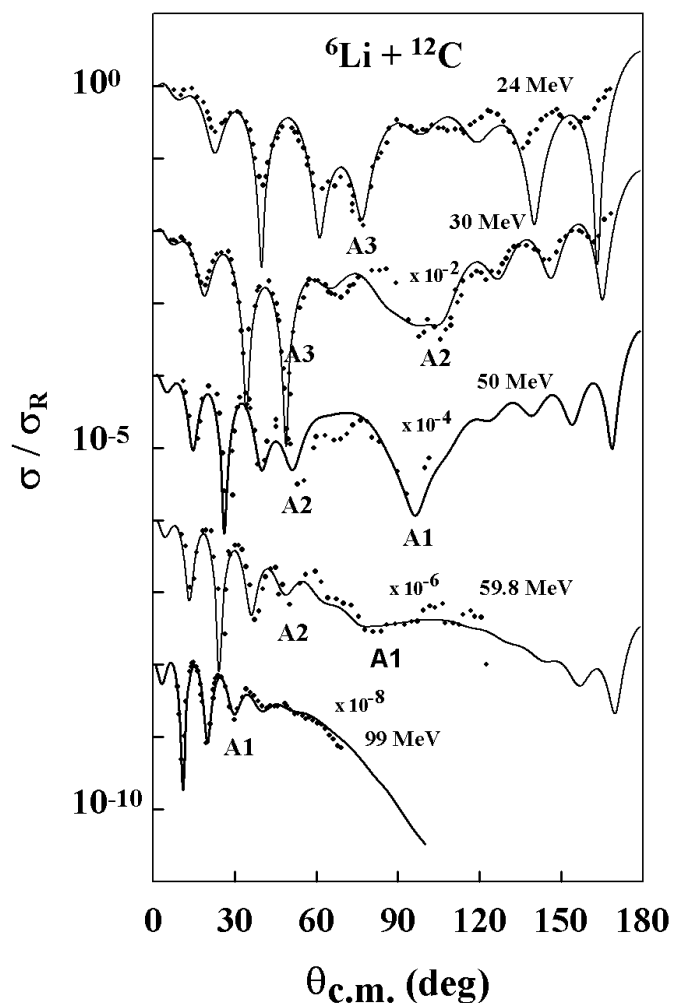


Fig. 2. Comparison of the global optical model ${}^6\text{Li}+{}^{12}\text{C}$ cross sections (solid lines) and the experimental angular distributions (filled circles). Airy minima are also indicated.

can be reproduced by a double folding model. A similar situation may be expected for ${}^6\text{He}$ scattering from ${}^{16}\text{O}$, ${}^{15}\text{N}$ and ${}^{14}\text{C}$, which will make it possible to determine the ${}^6\text{He}$ -nucleus potential for these systems.

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